

GEOCHEMICAL TYPOLOGY AND ORIGIN OF THE GRANITOID ROCKS OF WADI AKHDAR, CENTRAL-SOUTH SINAI.

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ABSTRACT

The granitoid rocks of Wadi Akhdar area are represented by comagmatic granodiorite, hornblende and biotite granites and biotite monzogranites. Mafic xenoliths and microxenoliths are relatively more abundant in the mafic granitoids. Variations within the granitoids reflect the degrees of separation of restites from the melt produced during fusion event.

Geochemically, the Akhdar granites show calc-alkaline affinity and they have similar ranges for alumina balance, alkali ratio, alkali/calcium ratio, normative feldspar, and trace elements distribution. They show remarkably similar degrees of differentiation and tectonic setting (volcanic arc granites "VAG", and orogenic granites type "OGT").

Geochronologically; in accordance with field relationships, the emplacement of the Akhdar granites has taken place almost simultaneously and at least three phases of granite magmatism are recognized.

The syn-collision granodiorite (older phase of granite magmatism), is deeply eroded, melanocratic and it ranges from mild metaaluminous to peraluminous, and it is poorly to moderately differentiated. In contrast, the younger phase of granite magmatism has been produced strongly differentiated melanocratic biotite-bearing granites.

Based on the obtained petrographic and geochemical data the magmas of the Akhdar pluton have been formed at 700-850 °C temperature and under 6-8 Kb. pressure. Probable petrogenesis of Akhdar granitoids should involve partial melting of meta-igneous rocks and fractional crystallization of the produced melts.

INTRODUCTION

The southern Sinai mapped area comprises rocks formed during the main Late Precambrian events [HASSEN, et al. (in press)]. The metamorphic series of Hebran-Solaf-Feiran belt of Sinai includes in addition to parametamorphic rocks, orthogneisses of granitic and dioritic compositions representing remnants of more or less four plutons. Generally, the plutonic rocks in south Sinai range in composition from gabbro to granite with some considerable occurrences of ultramafic intrusions.

Alkaline to subalkaline magmatic associations are represented by the Catherine ring series which comprises alkali rhyolite, quartz monzonites and quartz syenites (of the Catherine ring dyke) and biotite leucogranite (of the Catherine Pluton). Volcanic rocks of Gabal Abu-Durba (EL BYIALI, 1998), and the alkali granites of the Serbal-Sarabiel plutons, also belong to this magmatic series.

The Akhdar granitoids form a part of the Arabian-Nubian Shield and are characterized by the following associations; a) ortho- and para-gneisses of older shelf sequence, b) island arc assemblages, c) ophiolitic suites, and d) granitoid intrusives. In accordance, the Egyptian granitoid rocks have been classified in

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different ways into; „Grey granites” by EL-RAMLY and AKAAD (1960), the sheared cataclastic granites „Shaitian granites” described by SHURMANN (1953), „Synorogenic granites” by EL-SHAZLY (1964), „Older granites” by AKAAD and NUWEIR (1980), „Older and younger granitoids” by GASS (1979) and HASHAD (1980), and „Subduction related granites” by HUSSEIN et al (1982). The emplacement of the older granitoids have been occurred about 700-750 Ma (DIXON, 1979), and the younger granites, on the other hand have been emplaced in the restricted age 565-590 Ma (FULLAGAR and GREENBERG 1978).

This paper deals with the chemical and mineralogical variations, genesis, and the classification of the Akhdar granitoid pluton.

FIELD GEOLOGY

The distribution of Akhdar granitoids is shown in *Fig. 1*. The Akhdar granodiorite is well-known rock type of central south Sinai showing many significant geological characters. They are generally elliptical in outline and structurally discordant.

The granodiorite is grey, coarse-grained, porphyritic rock with extensive hornblende-rich dark green xenoliths and black spots of xenocrysts which show all stages of the resorption. The granodiorite locally manifests hybridization features, interpreted as a result of hybridization of Akhdar meta-gabbroid rocks and acidic magma. A gradual change can be observed in the east direction, where they became progressively decreased in the amounts of hornblende and xenoliths. They are enriched in biotite and alkali feldspar, while the porphyritic texture is gradually disappeared. Sometimes the boundaries of the xenoliths become indistinct and their colour becomes increasingly lighter.

The Akhdar granitoids are essentially massive but a weak foliation occurs in the more mafic and xenolith-rich types and near their contacts with metagabbro. The foliation results from the alignment of the mafic xenoliths (*Fig. 2*) and, the less commonly, by hornblende crystals. The xenoliths form platy to elliptical macroscopic enclaves of metagabbro-diorite complex varying in colour from grey to black. Their diameters are sometimes half meter but, more commonly, are less than 10 cm ranging down to microscopic dimensions. They frequently have ovoid shape, but sometimes they are angular. The boundaries between xenoliths and their host rocks are commonly sharp, and the xenoliths are surrounded sometimes by a zone of large K-feldspar crystals (up to 3 cm). All stages in xenolith disintegration can be observed.

Country rocks-related xenoliths are restricted to the immediate vicinity of the granitoid contacts. They are relatively medium grained and hornblende-bearing mafic types which relatively are common in the granodiorite exhibiting dark colour. There is a definite correlation between the abundance of xenoliths and the colour index of the host rock. Thus, they are rare in the more felsic rock types.

Hornblende-bearing mafic xenoliths are considered to be of local country rock origin, whereas, metagabbros and ortho-amphibolites are associated with the granitoids at present level of the exposure. All available field evidences imply that the xenoliths have been assimilated from gabbroid country rocks.

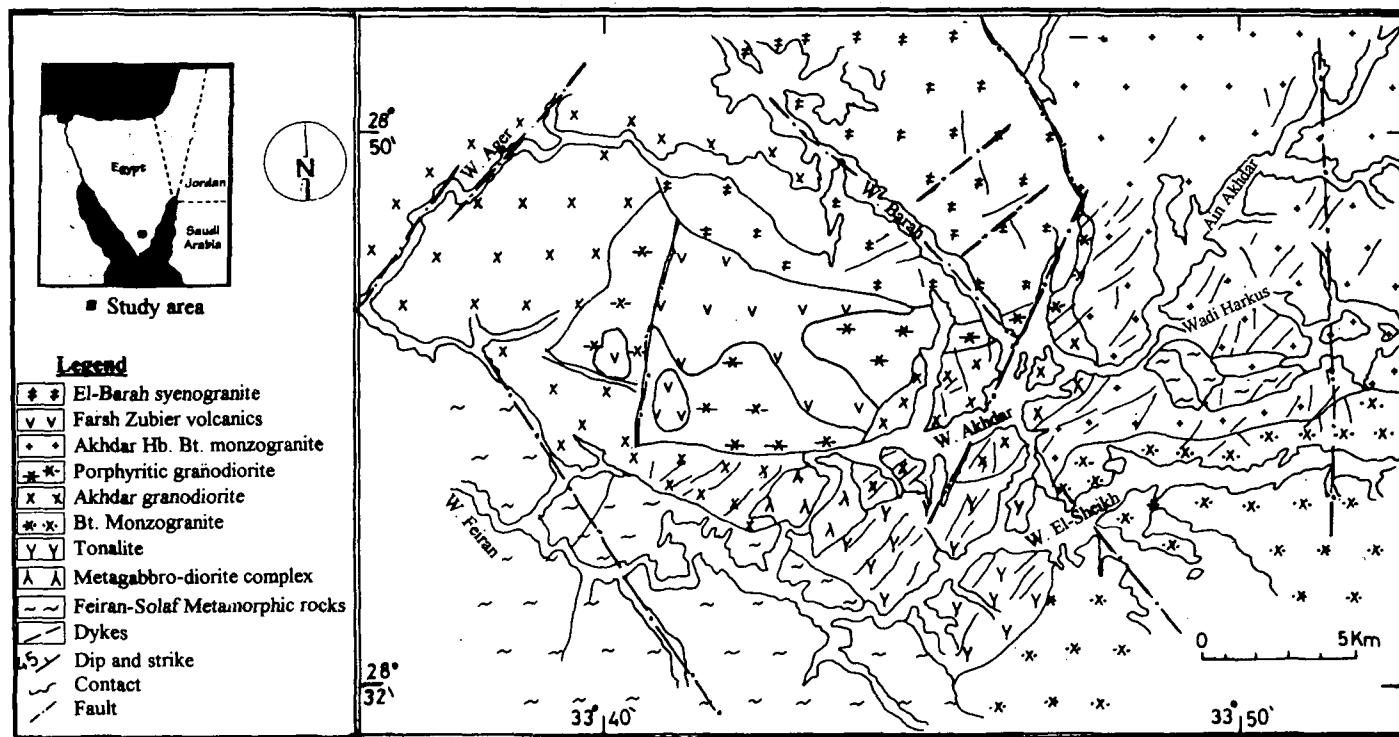


Fig.1. Geological Map of Wadi Akhdar Area

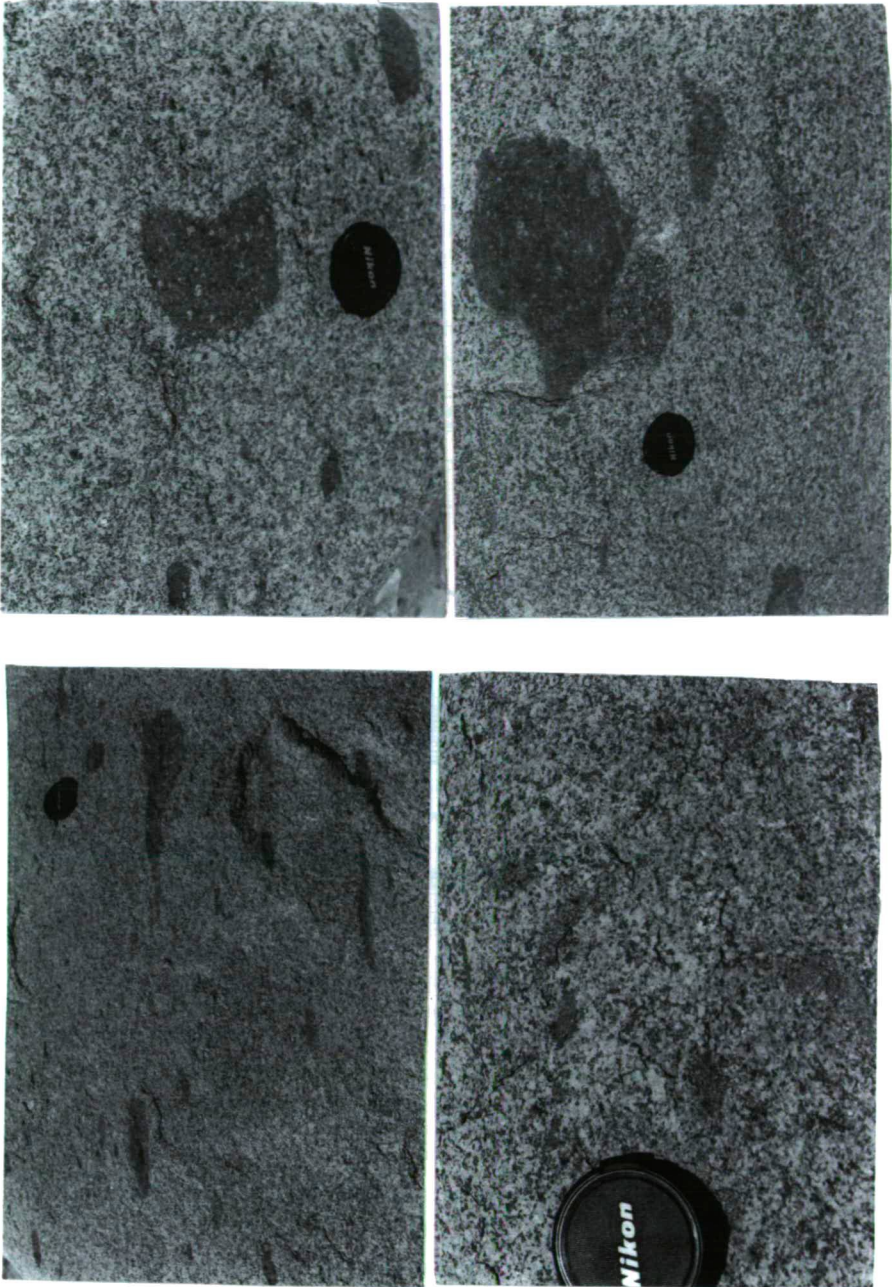


Fig. 2. The various types of magmatic mafic enclaves and xenocryst-rich mafic enclaves of the Akhdar granitoids, see also elongated enclaves and the two types of composite enclaves that are locally enclosed in the granitoid rocks

MODAL ANALYSES

The granitoid modes are plotted in terms quartz, K-feldspar and plagioclase (*Fig. 3*). The granitoids form a series ranging from granodiorite through adamellite and quartz-monzodiorite. Relatively, the younger granitoids are high in the K-feldspar content. Xenoliths usually consist of the same minerals as the host granitoids, with more abundant mafic minerals. Colour indices of the xenoliths range from 58 to 30 as the xenolith compositions merge toward those of the granitoids. The hornblende in the xenoliths from gabbroid country rock generally exceeds biotite in amount, but the relative amounts are related to the K-feldspar content. Spene content of the xenoliths is related in its occurrence to the host granitoids.

Petrographically, the Akhdar granitoids are coarse- to medium-grained rocks. The K-feldspars form the largest phenocrysts which frequently are pale pink and sometimes white in colour occurring in the granodiorite around the contact with the syenogranite.

The most significant textural feature of the granodiorite is the presence of „mantled” plagioclase crystals. They have a clouded core of relatively uniform composition riddled with alteration products. The core has rounded margins and surrounded by clear plagioclase, often with oscillatory zoning, passing out into normally zoned outer margins.

Rare clinopyroxene cores are found in the hornblende crystals of xenoliths near the contact with metagabbro. There is no other petrographic evidence of disequilibrium among the mafic minerals. In the felsic types; they contain very small amounts of hornblende, which occurs as a part of an equilibrium mineral assemblage. Another prominent textural feature is the occurrence of apatite as minute crystal, concentrated within the mafic minerals.

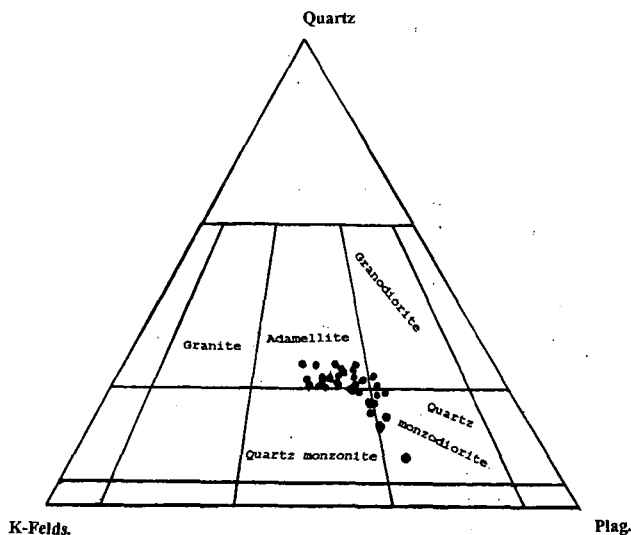


Fig. 3. Modal compositions (quartz, K-feldspar, plagioclase) of granitoid rocks from Wadi Akhdar. The classification used after STRECKEISEN et al. (1973). The upper limit for the quartz content of quartz-monzonite and quartz-monzodiorite is taken as 25% of the total quartz+felsdspar compared with the value of 20% chosen by the IUGS Subcommittee.

WHOLE ROCK GEOCHEMISTRY

The present study is based on 90 samples collected mainly from Wadi Akhdar. After a detailed thin sections study, 10 of the characteristic samples of the different rock types were selected for geochemical analysis with respect to the major, trace and rare earth elements (REE) in Budapest, Hungary using the XRF (for the major and trace elements) and the ICP (for REE) analytical techniques.

Granite typology

Several processes have been proposed to explain the geochemical various characters observed in granitoid plutons. WHITE and CHAPPELL (1977, 1983 and 1988) suggested the restite unmixing model as the main process responsible for such variations. WALL et al. (1987) critically examined the restite model and found that the criteria for the recognition of restite components are equivocal.

Nomenclature

According to the MIDDLEMOST (1985) diagram of SiO_2 (wt %) versus $\text{Na}_2\text{O} + \text{K}_2\text{O}$ (wt %), the Akhdar granitoids lie in the fields of the granodiorite and granite (Fig. 4a). Also, according to DEBON and LE FORT (1983) P-Q schemes (Fig. 4b), the Akhdar granitoids could be named either as granodiorite or tonalite rocks.

Petrochemical Trends

The alumina balance is calculated after DEBON and LA FORT (1983) as $\text{Al}(\text{Na}+\text{K}+2\text{Ca})$ and also after DE LA ROCHE (1980) as $2\text{Al}-(\text{Fe}+\text{Mg}+4\text{Ca}+2\text{Na}-\text{K})$. Considering these parameters, according to DEBON and LE FORT (1983), the studied Akhdar granitoids are mild metaaluminous to peraluminous affinity (Fig. 4c). In general, the alumina balance does not discriminate the granites sharply, however, relatively with differentiation, the granites are less peraluminous than they were in the early phase.

Colour index of granites is mainly controlled by the amount of biotite and is defined as the sum of $\text{Fe}+\text{Mg}+\text{Ti}$ (DEBON and LE FORT, 1983). The Akhdar granitoid plots are illustrated on Fig. 4c.

The alkali/calcium ratio is calculated as $(\text{Na}+\text{K})/\text{Ca}$. It shows that the Akhdar granodiorites are more calcic than the monzogranitic type. The younger granitic types are not separated from one another by this parameter (Table 1).

The geochemical trends define a systematic changes in particular in the granite types within a given batholith. In this respect several schemes were applied. The plots of the analysed granitic rocks on the (AFM) diagram proposed by IRVINE and BARAGAR (1971), they show calc-alkaline character and compression environment (Fig. 4d).

Granites may also be considered in terms of their lineage (ATHERTON, 1988), which includes source, intermediate evolution, and emplacement history, which may produce considerable variation at the level of exposure. These can be graphically summarised in terms of their normative components Qz-Ab-Or-An. Plots on the Qz-Ab-Or diagram (Fig. 5) compare the normative compositions of simple granite systems as determined by TUTTLE and BOWEN (1958), LUTH (1969) and JAMES and HAMILTON (1969). According to experimental studies, an increase in PH_2O shifts the minimum melting point toward the Ab apex, whereas, an increase in the An content under constant pressure produces the reverse effect, and hence this projection is only strictly applicable to low Ca granites. MANNING (1981, 1982) demonstrated that the presence of fluorine and boron in the Qz-Ab-Or- H_2O system will also cause a shift in the ternary minimum composition toward the Ab apex.

TABLE 1

Major, trace and rare-earth elements composition of Wadi Akhdar granitoid rocks

	1	2	3	4	5	6	7	8	9		
	Akh	Akh1	Akh2	Akh3	Akh4	Akh5	Akh6	Akh7	Akh8	mean &	std.dev
SiO ₂	65.97	68.75	66.95	72.87	66.93	65.39	71.96	70.96	67.96	68.638 ± 2.074	2.698
TiO ₂	0.74	0.58	0.58	0.42	0.52	0.55	0.35	0.29	0.24	0.474 ± 0.124	0.161
Al ₂ O ₃	15.32	15.22	14.85	14.23	15.98	15.47	14.72	13.78	15.20	14.975 ± 0.512	0.666
Fe ₂ O ₃	2.99	2.95	2.32	1.28	2.13	3.95	1.43	1.84	1.83	2.302 ± 0.659	0.857
FeO	0.97	1.91	1.97	0.65	1.79	1.43	1.24	0.88	1.22	1.340 ± 0.363	0.472
MnO	0.09	0.09	0.09	0.06	0.34	0.07	0.09	0.09	0.12	0.116 ± 0.066	0.086
MgO	1.67	1.39	1.23	0.69	1.28	1.35	0.91	0.89	1.51	1.213 ± 0.246	0.320
CaO	2.82	2.65	2.34	2.33	2.53	2.52	2.44	2.21	2.52	2.473 ± 0.124	0.161
Na ₂ O	4.42	4.74	4.65	3.79	4.63	3.95	4.45	4.17	4.66	4.384 ± 0.262	0.340
K ₂ O	3.09	2.19	2.39	3.45	3.19	3.04	3.56	3.22	3.48	3.068 ± 0.367	0.478
P ₂ O ₅	0.21	0.14	0.11	0.22	0.31	0.26	0.03	0.14	0.06	0.164 ± 0.071	0.093
LOI	0.56	0.44	0.40	0.57	0.59	0.96	0.22	0.38	0.76	0.540 ± 0.196	0.235
Cr	22.00	19.00	14.00	9.00	9.00	4.00	2.00	19.00	22.00	13.333 ± 5.879	7.649
Ni	15.00	13.00	13.00	10.00	15.00	29.00	7.00	32.00	33.00	18.556 ± 7.649	9.951
Co	9.00	6.00	8.00	3.00	6.00	20.00	3.00	14.00	18.00	9.667 ± 4.816	6.265
Sc	5.00	1.60	3.90	2.00	1.00	4.00	3.00	3.30	1.00	2.756 ± 1.098	1.428
V	87.00	51.00	49.00	8.00	43.00	39.00	23.00	35.00	33.00	40.889 ± 16.755	21.797
Cu	26.00	9.00	9.00	5.00	5.00	11.00	10.00	6.00	9.00	10.000 ± 4.907	6.384
Pb	30.00	18.00	17.00	22.00	13.00	11.00	19.00	24.00	21.00	19.444 ± 4.401	5.725
Zn	82.00	22.00	48.00	20.00	33.00	26.00	23.00	48.00	16.00	35.333 ± 16.147	21.006
Rb	59.00	78.00	89.00	110.00	99.00	95.00	141.00	82.00	122.00	97.222 ± 18.890	24.575
Cs	1.79	0.91	1.60	3.09	1.32	2.99	2.81	2.75	2.66	2.213 ± 0.624	0.811
Ba	950.00	1000.00	960.00	710.00	876.00	989.00	750.00	791.00	839.00	873.889 ± 82.727	107.624
Sr	611.00	626.00	635.00	422.00	650.00	544.00	246.00	475.00	539.00	527.556 ± 100.51	130.753
Ga	18.00	7.00	16.00	12.00	11.00	16.00	20.00	27.00	18.00	16.111 ± 4.440	5.776
Ta	0.03	0.02	0.04	0.03	0.05	0.03	0.52	0.12	0.06	0.520 ± 0.000	0.000
Nb	8.20	6.00	9.00	7.22	6.00	11.00	9.80	6.80	21.70	9.524 ± 3.747	4.875
Hf	5.30	8.00	4.90	2.61	2.11	3.50	3.80	2.12	4.90	4.138 ± 1.450	1.886
Zr	231.00	40.00	203.00	135.00	210.00	177.00	119.00	179.00	189.00	187.000 ± 31.017	40.352
Y	9.00	11.00	14.00	11.00	13.00	13.00	19.00	17.00	16.00	13.667 ± 2.461	3.202
Th	17.00	11.00	9.51	7.00	11.21	9.86	10.00	14.00	11.88	11.273 ± 2.202	2.865
U	5.00	6.00	5.30	4.00	8.40	2.50	3.10	4.43	2.44	4.574 ± 1.457	1.896
La	22.32	27.80	27.33	42.60	27.35	27.87	18.00	21.32	26.45	26.782 ± 5.298	6.892
Ce	44.00	52.00	57.43	69.87	48.60	53.07	33.96	56.87	57.40	52.578 ± 7.691	10.005
Nd	19.90	28.27	29.69	29.32	27.66	18.30	13.97	15.87	19.50	22.498 ± 4.771	6.207
Sm	3.64	4.88	4.39	3.66	4.33	5.37	3.22	4.43	4.37	4.254 ± 0.509	0.662
Eu	1.06	1.33	1.35	0.88	1.37	1.05	0.84	0.91	1.24	1.114 ± 0.164	0.213
Gd	3.02	4.96	3.59	2.56	3.68	2.22	1.92	1.32	2.41	2.909 ± 0.968	1.157
Tb	0.38	0.42	0.47	0.36	0.42	0.38	0.33	0.47	0.43	0.407 ± 0.037	0.048
Tm	0.25	0.23	0.23	0.25	0.24	0.23	0.22	0.24	0.25	0.238 ± 0.008	0.011
Yb	0.95	1.42	1.48	1.27	1.47	1.04	0.79	1.07	1.09	1.176 ± 0.189	0.246
Lu	0.18	0.24	0.26	0.22	0.26	0.24	0.22	0.21	0.25	0.23 ± 0.020	0.026
ΣREE	95.70	121.55	126.22	150.99	115.38	109.77	73.47	102.71	111.39	111.91 ± 16.46	21.41
La/Yb	23.49	19.58	18.47	3.35	18.61	26.80	22.78	19.92	24.27	22.11 ± 2.34	43.05
Sm/Tb	9.58	11.62	9.34	10.17	10.31	14.13	9.76	9.43	10.16	10.53 ± 1.17	1.52
Tb/Yb	0.4	0.30	0.32	0.28	0.29	0.37	0.42	0.44	0.39	0.35 ± 0.05	0.06
La/Sm	6.13	5.70	6.23	11.64	6.32	5.19	5.59	4.81	6.05	6.41 ± 1.56	2.03
La/Lu	124.00	115.83	105.12	193.64	105.19	16.13	81.82	101.52	105.80	116.56 ± 24.01	31.24

	1	2	3	4	5	6	7	8	9		
	Akh	Akh1	Akh2	Akh3	Akh4	Akh5	Akh6	Akh7	Akh8	mean &	std.dev
Eu/Sm	0.29	0.27	0.31	0.24	0.32	0.20	0.26	0.21	0.28	0.26 ± 0.03	0.04
Ce/Yb	46.32	36.62	38.80	55.02	33.06	51.03	42.99	53.15	52.66	45.52 ± 6.18	8.03
Ba/Cs	530.73	1098.90	600.00	229.77	663.64	330.77	266.90	287.64	315.41	480.42 ± 215.38	280.21
Ba/Sr	1.55	1.60	1.51	1.68	1.35	1.82	3.05	1.67	1.56	1.75 ± 0.39	0.50
Ba/Rb	16.10	12.82	10.79	6.45	8.85	10.41	5.32	9.65	6.88	9.70 ± 2.59	3.37
Rb/Sr	0.10	0.12	0.14	0.26	0.15	0.17	0.57	0.17	0.23	0.21 ± 0.11	0.14
Nb/Ta	0.00	0.00	0.00	0.00	0.00	0.00	18.85	0.00	0.00	18.85 ± 0.00	0.00
Th/U	3.40	1.83	1.79	1.75	1.33	3.94	3.23	3.16	4.87	2.81 ± 0.920	1.20
Zr/Hf	43.58	30.00	41.43	51.72	99.53	50.57	31.32	84.43	38.57	52.35 ± 18.41	23.94

TABLE 1 (contin.)
Major Element Composition Data and CIPW of Wadi Akhdar gneissoids.

	1	2	3	4	5	6	7	8	9	
	Akh	Akh1	Akh2	Akh3	Akh4	Akh5	Akh6	Akh7	Akh8	
SiO ₂	65.97	68.75	66.95	72.87	66.93	65.39	71.96	70.96	67.96	
TiO ₂	0.74	0.58	0.58	0.42	0.52	0.55	0.35	0.29	0.24	
Al ₂ O ₃	15.32	15.22	14.85	14.23	15.98	15.47	14.72	13.78	15.20	
Fe ₂ O ₃	2.99	2.95	2.32	1.28	2.13	3.95	1.43	1.84	1.83	
FeO	0.97	1.91	1.97	0.65	1.79	1.43	1.24	0.88	1.22	
MnO	0.09	0.09	0.09	0.06	0.34	0.07	0.09	0.09	0.12	
MgO	1.67	1.39	1.23	0.69	1.28	1.35	0.91	0.89	1.51	
CaO	2.72	2.65	2.34	2.33	2.53	2.52	2.44	2.21	2.52	
Na ₂ O	4.42	4.74	4.65	3.79	4.63	3.95	4.45	4.17	4.66	
K ₂ O	3.09	2.19	2.39	3.45	3.19	3.04	3.56	3.22	3.48	
P ₂ O ₅	0.21	0.14	0.11	0.22	0.31	0.26	0.03	0.14	0.06	
LOI	0.00	0.44	0.40	0.57	0.59	0.96	0.22	0.38	0.76	
Sum	98.19	101.05	97.88	100.56	100.22	98.94	101.40	98.85	99.56	
<i>CIPW norms</i>										
Q	19.94	24.20	23.16	31.89	20.25	22.65	25.85	28.16	19.64	
C	0.26	0.57	0.62	0.55	1.05	1.72	-	-	-	
Or	18.26	12.94	14.12	20.39	18.85	17.97	21.04	19.03	20.57	
Ab	37.40	40.11	39.35	32.07	39.18	33.43	37.66	35.29	39.43	
An	12.12	12.23	10.89	10.12	10.53	10.81	9.68	9.37	10.28	
Cpx	-	-	-	-	-	-	1.81	0.55	1.48	
Di	-	-	-	-	-	-	1.21	0.34	1.05	
Hd	-	-	-	-	-	-	0.60	0.21	0.43	
Opx	5.86	6.20	5.39	2.46	5.59	6.54	2.67	3.49	4.83	
En	4.16	3.46	3.06	1.72	3.19	3.36	1.70	2.06	3.28	
Fs	1.70	2.74	2.32	0.74	2.40	3.18	0.96	1.44	1.56	
Mt	2.46	2.94	2.60	1.21	2.49	3.22	1.75	1.71	1.98	
Il	1.41	1.10	1.10	0.80	0.99	1.04	0.66	0.55	0.46	
Ap	0.50	0.33	0.26	0.52	0.73	0.62	0.07	0.33	0.14	
Mg#:	56.80	46.65	46.72	52.87	50.88	43.26	52.55	50.71	61.54	
DI:	75.60	77.25	76.64	84.35	78.28	74.05	84.55	82.47	79.64	
SI:	35.32	42.46	40.42	53.47	35.02	39.19	44.17	48.13	34.78	
Alk rat.	2.43	2.27	2.39	2.55	2.46	2.27	2.75	2.72	2.70	
Ox. degr.	0.76	0.61	0.54	0.66	0.54	0.73	0.54	0.68	0.60	
Al/Alk	1.17	1.21	1.20	1.18	1.20	1.28	1.10	1.12	1.11	
Na+K/Ca	2.90	2.83	3.25	2.84	3.04	2.73	3.6	3.65	3.53	
Na/K	2.17	3.29	2.96	1.67	2.21	1.98	1.90	1.97	2.04	

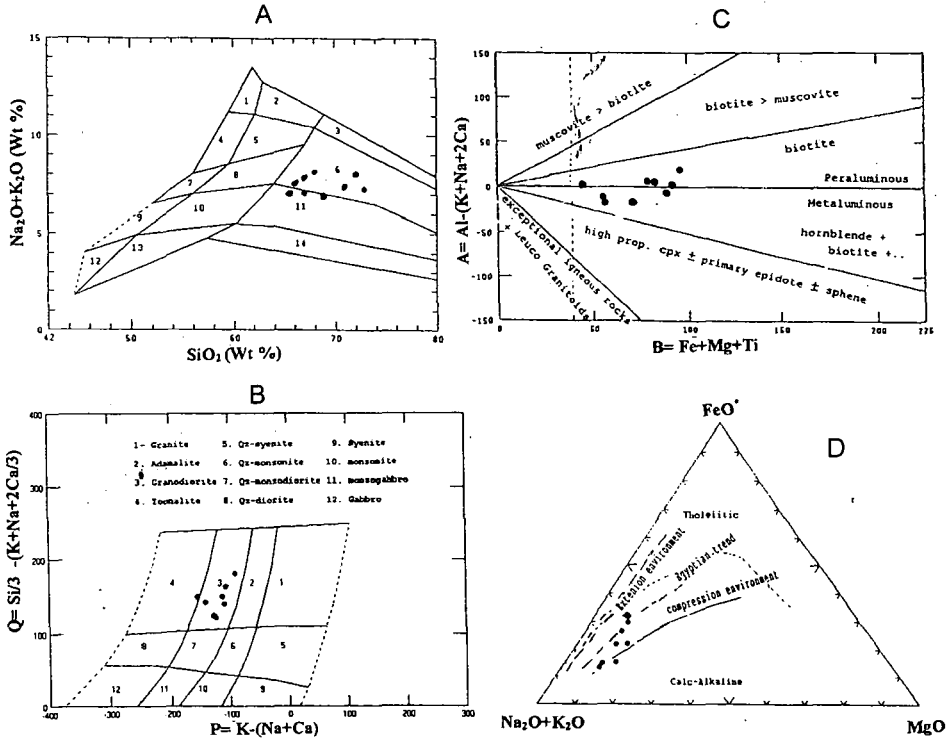


Fig. 4. A: SiO₂ Vs. Na₂O+K₂O diagram of Middlemost 1985. Classifying the Akhdar granitoids: 1. Alkali feldspar Syenite, 2. Alkali feldspar Quartz Syenite, 3. Alkali feldspar Granite, 4. Syenite, 5. Qz-Syenite, 6. Granite, 7. Monzonite, 8. Quartz Monzonite, 9. Monzodiorite, 10. Quartz Monzodiorite, 11. Granodiorite, 12. Diorite and Gabbro, 13. Qz-Diorite, 14. Tonalite.
 B: Q-P diagram of DEBON and LE FORT (1983). Molar proportions, where $Q = Si/3 - (K+Na-2Ca/3)$, $P = K/(Na+Ca)$.
 C: A-B variation plots of DEBON and LE FORT (1983) showing the plots of the Akhdar granitoids where, (A) = alumina saturation index $\{A = Al/(K+Na+2Ca)\}$ and (B) = color index $\{B = Fe+Mg+Ti\}$.
 D: AFM diagram of PETRO et al., (1979) Showing the trends for compressional suites and extensional environment. Tholeiitic and calc-alkaline fields after IRVINE and BARAGAR (1971). The Egyptian granites is defined after HUSSEN et al. (1982).

In order to interpret the crystallization feature of the granodioritic magma with experimental data available, if the water pressure at the initial crystallization of the magma is roughly equal to the rock pressure, i.e., the load pressure 5 Kb, the depth of initial crystallization was about 18 Km. However, masses of the magma from a parent body differentiating at depth might have moved up to a higher zone in the crust. Therefore, the crystallization of the magma mostly would have occurred at somewhat higher level with lower pressures than 5 Kb, that is equivalent of 18 Km depth. Accordingly, the normative minerals of Qz-Ab-Or for the granitic rocks are plotted in the tetrahedron Ab-An-Or-Qz (Fig.5). This diagram shows that the studied granitic

rocks as a group are distributed along the line m-n in the tetrahedron. The plots are located at the front face at 39% Ab, 58% An and 3% Or, and a point lies at the base of 30% Qz, 20% Or and 50% An. Therefore the crystallization of the granodioritic magma would be to crystallize the basic phase of the granitic rocks at around point m (about 1,100 ° of the H₂O saturated liquids), and continue to consolidate the magma along the m-n trend to the point n (about 600 °C).

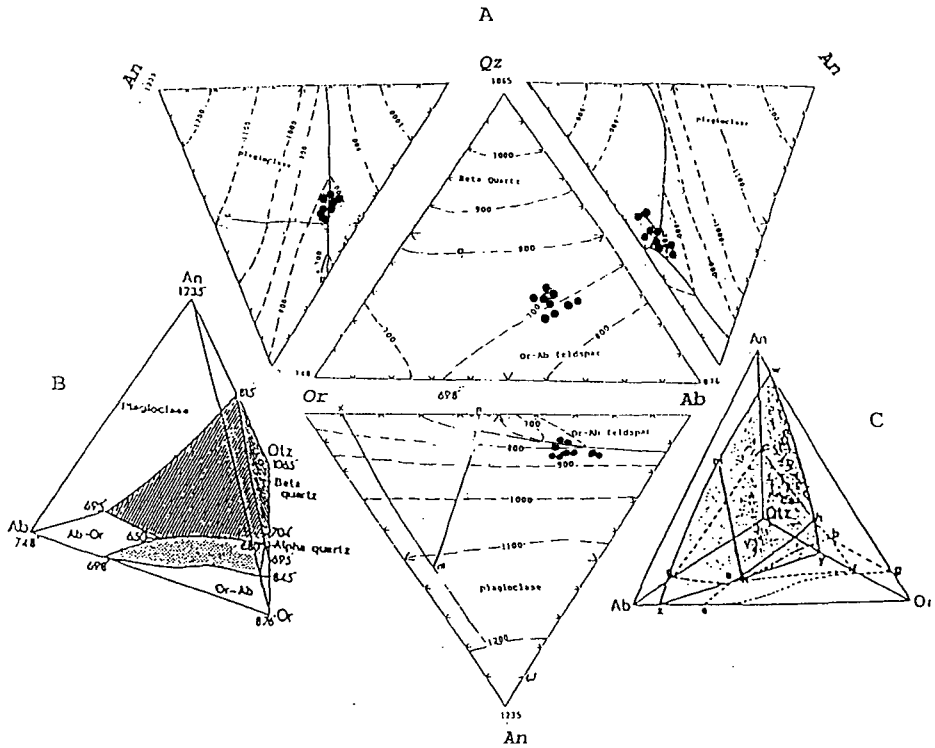


Fig. 5. The tetrahedron showing the liquids relation in the system Or-Ab-An-H₂O at 5 Kb H₂O pressure. All components are in weight percent.

A: Faces of the tetrahedron showing field boundaries (heavy lines), isotherms (light lines and dashes), and projections of norms of the granitic rocks of Wadi Akhadar area.

B: Three dimensional drawing of tetrahedron showing field boundaries. The minimum lies at 650 °C.

C: Section WXY, bisecting tetrahedron around Ab and An corner and intersecting the Or-Qz join at around midpoint. Projections of norms of the rocks show the generalized crystallization path of the granitic rocks, m-n on the section WXY.

GENETIC CLASSIFICATION

Alkali balance is a useful parameter in the genetic classification of granitoid rocks. This based on that; K and Na tend to show fluctuations both within and between major petrographical grouping, and commonly used as a geochemical discrimination between I- and S-type granitoids (CHAPPELL and WHITE, 1974; CHAPPELL and STEPHENS, 1988 and CHAPPELL and WHITE 1992). Considering HINE et al (1978), LE MAITRE, et.al (1982) and WHITE and CHAPPELL (1983), the plots of K_2O versus Na_2O (Fig. 6a) are used to show the compositional difference between I- and S-type for the studied granitoids. Notable exceptions to the use of the alkali balance as an I-S discrimination are; potassic calc-alkaline I-types which have an appreciable crustal component, and late stage metasomatic input or exchange such as observed in two phase derivatives of S-type granites (COBBING et al., 1986).

The model proposed by WHALEN et al, (1987), indicates that the Akhdar granitoids are mostly orogenic granite type (OGT) unfractionated granites, close to the line of dividing fractionated granites (FG). On the other hand, some other samples lie in the felsic fractionated granites field (Fig. 6b).

Tectonic discrimination of the Akhdar granitoids

The obtained field data indicated that the Akhdar granitoids pluton has been originated during a late kinematic regime. The tectonic setting of the Akhdar granitoids is illustrated on the following diagrams:

The Hf-Rb/30-TaX3 diagram of HARRIS et al. (1986), further separates pre-, syn-, and post-collision granites. On this diagram (Fig. 6c), the studied granitoid samples are plotted within the volcanic arc granite field (VAG). Also, on the Rb versus (Y+Nb) diagram (Fig. 6d) proposed by PEARCE et al (1984), the Akhdar granitoids plots fall within the volcanic arc granite (VAG) field.

On the multi-element, MORB-normalized diagram (Fig. 6e), the Akhdar granitoids are characterized by enrichment of the LIL elements (K_2O , Rb, Ba and Th) relative to the HFS-elements (Ta, H, Zr, Y and Yb). A typical feature of most of the granitoid samples as their negative Ta-anomalies.

The chondrite-normalized REE diagrams of the Akhdar granitoids are shown in the Fig. 6f) where the Wadi Akhdar granitoid samples show similar patterns. The Sm/Tb_n defined by the MREE (average $La/Sm_n = 6.41 \pm 1.56$ and $Tb/Yb_n = 0.35 \pm 0.05$) and all samples show no negative Eu-anomaly (Table 1). The low REE patterns of the studied granitoid rocks indicate close petrogenetic histories, which will be briefly discussed. Firstly we considered the gabbroid xenoliths-bearing granodiorite rocks which are the representative of melts from which the granitoid rocks might developed by fractional crystallization. The slope of the REE patterns of these rocks without Eu-anomaly reflects the fractionation to yield silic magma which would be dominated by removal of plagioclase, and thus of formed by partial melting of plagioclase-rich rocks, or alternatively have undergone plagioclase accumulation. Those with LREE-enriched patterns, characterized with no negative Eu-anomalies would be compatible with generation by partial melting of mafic source, in which amphibole/or garnet is present as residual phases in the source material (HANSON, 1978).

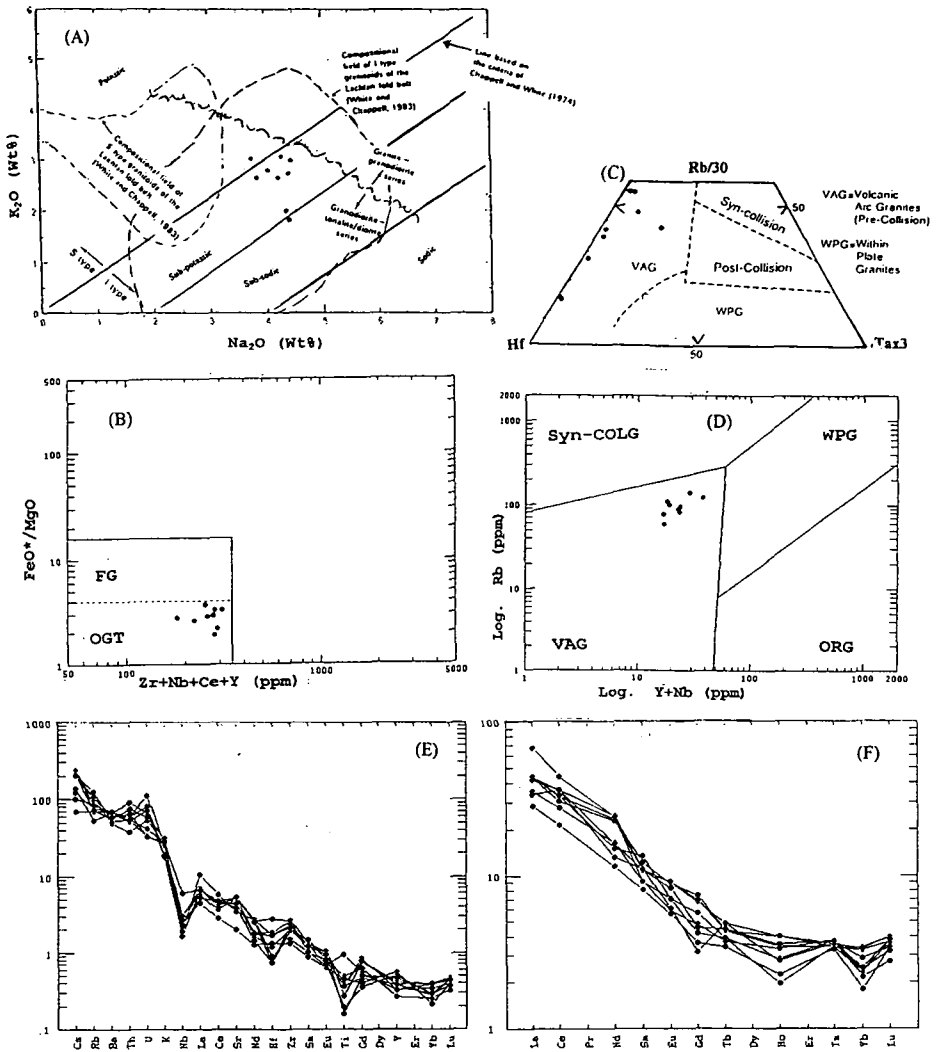


Fig. 6. A: K_2O Vs. Na_2O variation diagram after LE MAITRE, et al. (1982). I-S type after HINE et al., (1978). Compositional field of I- and S-type granitoids after WHITE and CHAPPEL (1983)
 B: $Zr+Nb+Ce+Y$ Vs. FeO^*/MgO binary diagram of WHALEN et al., (1987). FRAC is the compositional field of the highly fractionated I- and S-types.
 C: Ternary diagram of Wadi Akhdar granitoids rocks plotted in $Hf-Rb/30-Tax3$ after HARRIS et al. (1986).
 D: Trace element tectonic discrimination plots of the examined granitoids. Fields are after PEARCE et al. (1984). VAG = Volcanic arc granite; ORG = Ocean ridge granite; WPG = Within plate granite; SCG = Syn-Collision granite
 E: Discrimination diagram showing the Akhdar granitoid geochemical patterns. The data was treated due to those proposed by THOMPSON (1982).
 F: Chondrite normalized REE distribution patterns of the Wadi Akhdar granitoids, THOMPSON (1982).

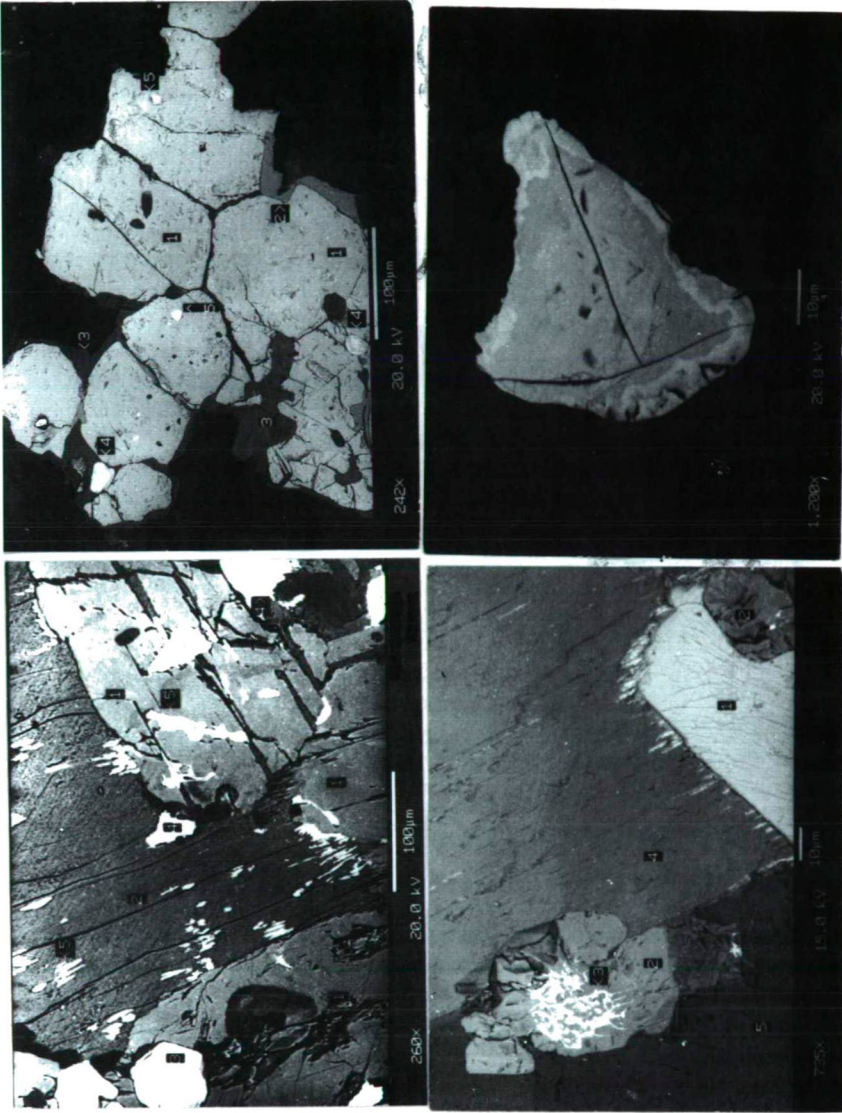


Fig. 7. Microphotographs (SEM): (A) showing 1. Fe-Oxides, 2. ilmenite, 3. titanite, 4. zircon and 5. sphalerite, B (showing) 1. amphibole, 2. albite, 3. apatite, 4. zircon and 5. sphalerite, (C) showing 1. allanite, 2. apatite, 3. Th+REM, 4. biotite and 5. plagioclase, and (D) showing thorite crystals

PETROGENESIS AND ORIGIN

The composition of the Akhdar granitoid rocks suggest that the oxygen fugacity and partial melting favours a define role in the formation of granitoid rocks of Wadi Akhdar. The presence of metagabbro and orthogneiss as a roof pendant and xenolith in the

country rocks (*Fig.2*) and hornblende, biotite, magnetite, Fe-oxides, sphalerite and allanite (*Fig. 7a,b and c*) may indicate I-type magma composition for the source rock.

Petrographical and geochemical observations suggest that the initial melt for the considered granites was generated in a water saturated system.

JOHANNES and HOLTZ, (1990 and 1991) found that an initial magma with 50% melt plus 50% quartz and feldspar would occur at 700°C to 900 and 8 Kb pressure, in a closed system. This temperature accords with zircon thermometry, which indicates 800 °C for the initial crystallization of the melt in the older granites (BUDA, et al., 1998). The amount of melt at given P-T conditions would depend upon the availability of water

It seems that in the later stages, an addition of a fluids to the subsolidus granite magma might have occurred, i.e. the second phase of the Akhdar granitoids emplacement as monzogranite type.

The source of suchs fluids can give rise and associated with Fe-oxides, sphalerite Th and rare-earth minerals (REM) mineralization at Ain Akhdar (*Fig. 7C and D*).

The intrusion level of the older types can be determined with less confidence than the younger types, because the former is deeply eroded, whereas, the roof zones of the younger granites are still preserved. In general, the roof of the younger types lies nearly parallel to the present surface at many places. The granitic intrusion can be assumed to have been emplaced at depths of between 5 and 8 Km.

CONCLUSIONS

All evidences available from the field observations implied that the xenoliths have been assimilated from gabbroid country rocks. There is no other petrographic evidence of disequilibrium among the mafic minerals. In the felsic types; they contain very small amounts of hornblende which occurs as a part of an equilibrium mineral assemblage. The enclaves are generally hornblende-bearing variety consistant with those of the I-types.

From the major elements geochemistry, the studied granitoid rocks can be classified as granodiorite, tonalite and monzogranite. They are alumino-caffemic magmatic association of mild metaaluminous - peraluminous character and biotite-rich, showing calc-alkaline character and compression environment.

The trace element geochemistry encountered pronounced negative Ta and Nb anomalies. similar to that of volcanic arc granites (VAG) (PEARCE et al., 1984 and HARRIS et al., 1986) originated during late kinematic regime. The VAG is probably formed in a late tectonic environment dealing with crustal rather than mantle source.

The light REE patterns of the studied granitoid rocks indicate close petrogenetic histories. The slope of the REE patterns of these rocks without Eu-anomaly reflects the fractionation to yield silicic magma which would be dominated by removal of plagioclase, and thus of formed by partial melting of plagioclase-rich rocks, or alternatively have undergone plagioclase accumulation. Those with LREE-enriched patterns, characterized with no negative Eu-anomalies would be compatible with generation by partial melting of mafic source.

Petrographical and geochemical observations suggest that the later stages, and the addition of fluids to the subsolidous granite magma might have occurred. The source of such a fluid, can give rise and associated with Zn, Th and rare-earth metals (REM) mineralization.

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